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Forest Science Program

044

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Louise de Montigny and Gordon Nigh

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ABSTRACT

Survival and height, diameter at breast height (dbh), volume, and crown growth of Douglas-fir and western redcedar in a mixed plantation were measured 14 years after planting. As expected, Douglas-fir had faster early growth than western redcedar and average dbh, volume, and crown area of the stand increased as the proportion of Douglas-fir in the stand increased. However, the average growth of Douglas-fir and western redcedar was not significantly different when grown in a pure stand compared to being grown in a mixed stand. Average growth of either species was also not significantly different at densities of 500, 1000, or 2000 stems per hectare. Consequently, at this young age, the effect of the species mixtures on growth was likely due to different early growth rates rather than from differences between interspecific and intraspecific competition. This experiment will help to determine the long-term outcomes of different stand mixtures in producing timber volume.

Key words: crown area, diameter growth, height growth, mixed species, volume.

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CONTENTS

1 INTRODUCTION

When timber yield is the primary forest management objective, plantation monocultures have been favoured. However, the uncertainty about the effects of climate change emphasizes the need to evaluate a range of existing and new forest management approaches for their ability to maintain and enhance ecological resilience and ecosystem services, products, and benefits under changing ecological conditions (Weese 2007). Planting of species mixtures may improve ecosystem resilience by offering some protection from disease and insect outbreaks, resistance to wind damage and other abiotic stresses, and conservation of native plant and animal species. The resulting lower timber yields are considered a necessary sacrifice that accompanies the use of mixtures unless the species have good ecological combining ability—that is, the differences in growth characteristics reduce competition or one species has a positive effect on the growth of the other species (Kelty 1992).

Ecological theory suggests that two or more species having very different growth characteristics such as height, form, photosynthetic efficiency of foliage, and root structure may have a good ecological combining ability, which allows them to coexist in mixtures with high productivity (Harper 1977). This ability to coexist may largely be the result of niche separation, such as canopy or root stratification in mixtures compared to monocultures, which allows resources to be used more effectively. Understanding these relationships between species may enable silviculturists to design specific mixtures that provide ecosystem resilience while maintaining or surpassing timber yields or other ecosystem goods and services from monocultures.

Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) and western redcedar (*Thuja plicata* Donn *ex* D. Don *in* Lamb) are recommended for planting together on many sites throughout the Coastal Western Hemlock zone in British Columbia (Green and Klinka 1994) and may be a species mix with good ecological combining ability. The two species have very different growth characteristics: Douglas-fir has rapid early height growth with strong epinastic control with determinate growth that is typical of a shade-intolerant species; western redcedar has a slow early height growth with weak epinastic control, has indeterminate growth, and is shade-tolerant (Oliver and Larson 1996).

Root system morphology may also be different between the species. Eis (1987) concluded that Douglas-fir and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) had similar root system morphology and that western redcedar had the densest root system and the shortest lateral roots of these three species. Wang et al. (2002) studied the root systems in stands of pure western hemlock and western redcedar and mixtures of these species. They found that in pure stands the root density of western redcedar peaked in the uppermost mineral soil, while root density of western hemlock decreased from the forest floor down to a depth of 20 cm. Compared to hemlock, western redcedar had a much greater proportion of fine and medium roots than coarse roots. When comparing mixed stands of the two species, mixtures had greater root density across all soil layers than did pure stands. Western redcedar roots are more resistant to *Armillaria* root disease than other conifers and including higher proportions of western redcedar when planting infested sites may reduce the overall impact of this disease (Van Der Kamp 2005).

Douglas-fir and western redcedar foliar and soil nutrition are also quite different; therefore, combining these two species may lead to more effective nutrient cycling. Western redcedar foliage and litter have higher levels of calcium (Radwan and Harrington 1986) relative to other conifer species. This may be attributed to western redcedar's ability to accumulate calcium in excess of its nutrient requirements, thereby acting as a calcium pump to the site (Weetman et al. 1987). Forest floor nutrient concentrations of this nutrient were highest under western redcedar and lowest under western hemlock, with Sitka spruce (*Picea sitchensis* [Bong.] Carr.) and Douglas-fir being intermediate; rates of nitrogen mineralization tended to be greater in forest floors under western redcedar than for the other species (Prescott et al. 2000). Soil organism populations are also affected by tree species. Collembolan, oribatid mites, and macrofungal species were noticeably less prevalent under western redcedar compared to Sitka spruce, Douglas-fir, or western hemlock (Berch et al. 2001).

Decisions about planting mixtures require an understanding of the survival and growth rates of the different species when grown together at different spacings; too many trees of either species may result in volume loss to overcrowding and mortality. The experiment described in this report examines the effects on growth and development of Douglas-fir and western redcedar after 14 years when grown at 500, 1000, or 2000 stems per hectare in Douglas-fir–western redcedar mixes of 1:0, 1:1, 1:3, and 0:1.

2 STUDY AREA

The site chosen for this experiment was near Sooke, B.C. in the eastern variant of the Coastal Western Hemlock very dry maritime (CWHxm1) biogeoclimatic subzone (Meidinger and Pojar 1991). The CWHxm1 occurs at lower elevations along the east side of Vancouver Island and has warm, dry summers and moist, mild winters with relatively little snowfall; growing seasons are long and feature water deficits on zonal sites (Green and Klinka 1994). The soil moisture regime was mostly fresh with some moist areas and the soil nutrient regime was medium and rich corresponding to site series 01 (western hemlock, Douglas-fir, and *Kindbergia oregana*) and 07 (western redcedar and foamflower [*Tiarella trifoliata*]) (Green and Klinka 1994). Douglas-fir and western redcedar regenerate well on the 07 site series, whereas on the 01 site series, Douglas-fir usually performs better than western redcedar (Green and Klinka 1994).

3 TRIAL LAYOUT AND DATA COLLECTION

The experiment was established early in the spring of 1992 as a 4×3 factorial design with four levels of species mixtures and three levels of density (spacing). Table 1 shows the specific treatments. The plots were eight trees by eight trees with an additional buffer two trees wide. A fence protected the plots from deer browsing. The experiment was established as a factorial design replicated in two blocks; however, due to space limitations, two plots in one block were established in the other block. Ecosystem classification indicated variability in the moisture regimes within one block. Given that the plots were not blocked properly and that a preliminary analysis of the block effect (not reported) showed that the effect was small, we treated the experiment as a 4×3 factorial with two repetitions. Initial plot measurements were made in the fall of 1992 and remeasurements were done in the fall of 1993, 1994, 1995, 1997, 1999, 2001, and 2006.

The trees in the 1:1 mixture were planted in an alternating pattern. The trees in the 1:3 mixture were planted as one row of a 1:1 mixture and the adjacent row as pure western redcedar. All trees were two years old at the time of planting. For subsequent remeasurement, all trees were tagged. Measurements taken included species, height (m), diameter (cm) at breast height (1.3 m) (dbh), crown radii (m) in the four cardinal directions, and vigour (healthy, poor, dead, missing). Root collar diameter was not measured.

TABLE 1 *Treatments applied in this experiment*

Density		Douglas-fir : western redcedar mixtures (stems per hectare)			
Tree spacing (m)	Stems per hectare	1:0	1:1	1:3	0:1
4.47	500	500:0	250:250	125:375	0:500
3.16	1000	1000:0	500:500	250:750	0:1000
2.24	2000	2000:0	1000:1000	500:1500	0:2000

4 ANALYSIS

We were interested in differences in height, dbh, volume, and crown growth and survival between the different treatments. Therefore, we only analyzed the data collected in 2006. To convert height to height growth, we subtracted the initial height of the trees in 1992. Since all trees were below breast height when the experiment was initiated, the measured dbh in 2006 represents diameter growth. We calculated volume v (m^3) as:

$$v = 0.42 \times h \times \pi \times (dbh / 2)^2$$

where: h = height (m) and dbh = diameter at breast height (m). This is simply the volume of a cylinder with a height h and a diameter of dbh multiplied by a form factor (Husch et al. 2003). The form factor of 0.42 is arbitrary but

reasonable. The choice of form factor does not affect the analysis because the ANOVA model is linear. Projected crown area ca (m^2) was calculated as:

$$ca = [(cre + crs + crw + crn) / 4]^2 \times \pi$$

where: cre, crs, crw, crn are crown radius (m) in the east, south, west, and north directions, respectively. Individual tree height growth, dbh, volume, and crown area were averaged for each plot. We calculated survival (s) as the number of trees remaining in 2006 divided by the number of trees planted in 1992.

The ANOVA model is:

$$y = \mu + M + D + M \times D + \varepsilon$$

where: $y = h$, dbh, v, ca, or s; M is the effect due to species mixture; D is the effect due to density; and ε is the random error term. We used planned linear contrasts (Table 2) to test whether the effects of the treatments were linear across the treatments. As well as analyzing both species combined, we also analyzed each species separately. When analyzing the species separately, the number of levels of mixture was reduced because the data for one level of mixture drop out. The regression assumptions were tested using scatter plots of the residuals to confirm homoscedasticity and Shapiro and Wilk's (1965) w statistic to confirm normality in the residuals. The least significant difference method with Sidak's (1967) correction was used to make pairwise comparisons between the treatments, and to control the overall type I error rate. Pairwise comparisons compare the responses across all treatment levels on a pairwise basis to determine which responses are statistically different.

TABLE 2 *Linear contrasts to determine whether effects were linear across the treatments*

Treatment	Levels	Contrast
Both species		
Density	500; 1000; 2000	-4; -1; 5
Mixtures[a]	100; 75; 50; 0	7; 3; -1; -9
Western redcedar		
Density	500; 1000; 2000	-4; -1; 5
Mixtures[a]	100; 75; 50	-1; 0; 1
Douglas-fir		
Density	500; 1000; 2000	-4; -1; 5
Mixtures[b]	25; 50; 100	-4; -1; 5

a percent western redcedar
b percent Douglas-fir

The results of the ANOVAs for dbh, height growth, volume, crown area, and survival after 14 years post-planting are presented in Tables 3, 4, 5, 6, and 7, respectively. These tables also show the results of the linear contrasts. All statistical tests were carried out at the 5% level of significance ($\alpha = 0.05$). The W statistic and scatter plots (not presented) indicated that the residuals were normally distributed and homoscedastic for all analyses. Table 8 shows the average dbh, height growth, volume, crown area, and survival for the two treatments by species. In this table, a common superscripted letter indicates averages that are not significantly different.

TABLE 3 *Results of the ANOVAs for dbh*

Species	Treatment	Degrees of freedom	Sum of squares	Mean square	F-value	p > F
Both	Density	2	929	464	0.65	0.54
	Linear contrast	1	896	896	1.26	0.28
	Mixture	3	20 947	6982	9.80	< 0.01
	Linear contrast	1	19 649	19 649	27.57	< 0.01
	Density × mixture	6	7321	1220	1.71	0.20
	Error	12	8554	713		
Western redcedar	Density	2	1860	930	1.33	0.31
	Linear contrast	1	1154	1154	1.65	0.23
	Mixture	2	1429	714	1.02	0.40
	Linear contrast	1	67	67	0.10	0.77
	Density × mixture	4	2196	549	0.78	0.56
	Error	9	6299	670		
Douglas-fir	Density	2	396	198	0.38	0.70
	Linear contrast	1	211	211	0.40	0.54
	Mixture	2	1833	916	1.74	0.23
	Linear contrast	1	1667	1667	3.17	0.11
	Density × mixture	4	7636	1909	3.63	0.05
	Error	9	4732	526		

TABLE 4 *Results of the ANOVAs for height growth*

Species	Treatment	Degrees of freedom	Sum of squares	Mean square	F-value	p > F
Both	Density	2	561	281	0.01	0.99
	Linear contrast	1	499	499	0.02	0.88
	Mixture	3	90 6224	30 2075	13.69	< 0.01
	Linear contrast	1	88 4811	88 4811	40.10	< 0.01
	Density × mixture	6	20 4523	34 087	1.54	0.25
	Error	12	26 4771	22 064		
Western redcedar	Density	2	45 527	22 764	1.26	0.33
	Linear contrast	1	18 403	18 403	1.02	0.34
	Mixture	2	42 406	21 203	1.17	0.35
	Linear contrast	1	2041	2041	0.11	0.75
	Density × mixture	4	41 816	10 454	0.58	0.69
	Error	9	162 575	18 064		
Douglas-fir	Density	2	13 692	6846	0.34	0.72
	Linear contrast	1	12 570	12 570	0.63	0.45
	Mixture	2	3951	1975	0.10	0.91
	Linear contrast	1	657	657	0.03	0.86
	Density × mixture	4	177 599	44 400	2.23	0.15
	Error	9	179 360	19 929		

TABLE 5 *Results of the ANOVAs for volume*

Species	Treatment	Degrees of freedom	Sum of squares	Mean square	F-value	p > F
Both	Density	2	0.0002635	0.0001318	0.30	0.74
	Linear contrast	1	0.0001195	0.0001195	0.27	0.61
	Mixture	3	0.01321	0.004403	10.11	< 0.01
	Linear contrast	1	0.01304	0.01304	29.94	< 0.01
	Density × mixture	6	0.006052	0.001009	2.32	0.10
	Error	12	0.005225	0.0004354		
Western redcedar	Density	2	0.0002131	0.0001065	0.91	0.44
	Linear contrast	1	0.0001436	0.0001436	1.23	0.30
	Mixture	2	0.0001317	0.0000659	0.56	0.59
	Linear contrast	1	0.0000046	0.0000046	0.04	0.85
	Density × mixture	4	0.0004378	0.0001094	0.94	0.49
	Error	9	0.001053	0.0001170		
Douglas-fir	Density	2	0.0008569	0.0004284	0.62	0.56
	Linear contrast	1	0.0001906	0.0001906	0.27	0.61
	Mixture	2	0.002067	0.001033	1.49	0.28
	Linear contrast	1	0.001418	0.001418	2.04	0.19
	Density × mixture	4	0.01035	0.002587	3.72	0.05
	Error	9	0.006255	0.0006950		

TABLE 6 *Results of the ANOVAs for crown area*

Species	Treatment	Degrees of freedom	Sum of squares	Mean square	F-value	p > F
Both	Density	2	24.53	12.27	1.52	0.26
	Linear contrast	1	20.59	20.59	2.55	0.14
	Mixture	3	229.00	76.33	9.44	< 0.01
	Linear contrast	1	207.98	207.98	25.73	< 0.01
	Density × mixture	6	125.40	20.90	2.59	0.08
	Error	12	97.01	8.08		
Western redcedar	Density	2	13.23	6.62	1.24	0.34
	Linear contrast	1	10.43	10.43	1.95	0.20
	Mixture	2	15.14	7.57	1.42	0.29
	Linear contrast	1	0.34	0.34	0.06	0.81
	Density × mixture	4	17.40	4.35	0.81	0.55
	Error	9	48.13	5.35		
Douglas-fir	Density	2	17.87	8.94	0.84	0.46
	Linear contrast	1	12.93	12.93	1.22	0.30
	Mixture	2	74.37	37.19	3.51	0.07
	Linear contrast	1	65.79	65.79	6.21	0.03
	Density × mixture	4	179.10	44.78	4.22	0.03
	Error	9	95.43	10.60		

TABLE 7 *Results of the ANOVAs for survival*

Species	Treatment	Degrees of freedom	Sum of squares	Mean square	F-value	p > F
Both	Density	2	0.004049	0.002024	0.18	0.84
	Linear contrast	1	0.001817	0.001817	0.16	0.69
	Mixture	3	0.05976	0.01992	1.78	0.20
	Linear contrast	1	0.000879	0.000879	0.08	0.78
	Density × mixture	6	0.01491	0.002485	0.22	0.96
	Error	12	0.1342	0.01118		
Western redcedar	Density	2	0.000365	0.000182	0.02	0.98
	Linear contrast	1	0.000326	0.000326	0.03	0.86
	Mixture	2	0.03705	0.01852	1.95	0.208
	Linear contrast	1	0.02352	0.02352	2.48	0.15
	Density × mixture	4	0.01988	0.004970	0.52	0.72
	Error	9	0.08548	0.009497		
Douglas-fir	Density	2	0.01093	0.005466	0.18	0.84
	Linear contrast	1	0.01089	0.01089	0.37	0.56
	Mixture	2	0.09557	0.04778	1.60	0.25
	Linear contrast	1	0.08092	0.08092	2.72	0.13
	Density × mixture	4	0.02007	0.005018	0.17	0.95
	Error	9	0.2682	0.02980		

TABLE 8 *Pairwise comparisons between the treatments. Treatment averages with different superscripted letters are significantly different.*

		Density			Mixture			
Species	**Parameter**	**500**	**1000**	**2000**	**0:1**	**1:3**	**1:1**	**1:0**
All	dbh	10.4^{a}	9.7^{a}	8.9^{a}	5.4^{a}	9.4^{ab}	10.2^{ab}	13.7^{b}
	Height	6.62^{a}	6.54^{a}	6.50^{a}	4.02^{a}	6.07^{a}	6.66^{a}	9.46^{b}
	Volume	0.045^{a}	0.038^{a}	0.039^{a}	0.010^{a}	0.033^{a}	0.043^{ab}	0.076^{b}
	Crown area	9.97^{a}	8.29^{a}	7.56^{a}	3.98^{a}	8.51^{ab}	9.32^{b}	12.63^{b}
	Survival	0.87^{a}	0.89^{a}	0.89^{a}	0.95^{a}	0.82^{a}	0.86^{a}	0.90^{a}
Western redcedar	dbh	6.5^{a}	7.3^{a}	4.9^{a}	5.4^{a}	7.5^{a}	5.9^{a}	
	Height	4.47^{a}	5.11^{a}	3.88^{a}	4.02^{a}	5.16^{a}	4.28^{a}	
	Volume	0.013^{a}	0.015^{a}	0.007^{a}	0.010^{a}	0.015^{a}	0.009^{a}	
	Crown area	5.24^{a}	5.54^{a}	3.59^{a}	3.98^{a}	6.07^{a}	4.32^{a}	
	Survival	0.89^{a}	0.89^{a}	0.90^{a}	0.95^{a}	0.85^{a}	0.86^{a}	
Douglas-fir	dbh	14.9^{a}	15.4^{a}	14.2^{a}		16.2^{a}	14.7^{a}	13.7^{a}
	Height	8.96^{a}	9.36^{a}	9.63^{a}		9.38^{a}	9.11^{a}	9.46^{a}
	Volume	0.082^{a}	0.094^{a}	0.077^{a}		0.100^{a}	0.079^{a}	0.076^{a}
	Crown area	15.29^{a}	15.82^{a}	13.49^{a}		17.55^{a}	14.42^{a}	12.63^{a}
	Survival	0.80^{a}	0.82^{a}	0.86^{a}		0.73^{a}	0.85^{a}	0.90^{a}

Density did not have a significant effect on dbh, height, volume, crown area, or survival when all trees in the plot were considered, or when the two species were analyzed separately. When both species were analyzed together, the species mixture did have a significant effect on dbh, height growth, volume, and crown area, but not on survival. Diameter, height growth, volume, and crown area all increased linearly (as determined by the linear contrast) as the proportion of Douglas-fir in the plot increased. However, when both species were analyzed separately, we found no difference in these variables across the treatments. An interaction effect was evident for dbh, volume, and crown area when the Douglas-fir data were analyzed separately; however, these interactions were the result of one or two plots with irregular data and the interaction term was only slightly significant ($p \geq 0.03$). Therefore, we will scrutinize future data and results to ascertain whether the interaction effect is significant or whether these plots are anomalous.

The pairwise comparisons for the mixed species treatment when analyzed for all species showed that for dbh, the 100% western redcedar plots were different from the 100% Douglas-fir plots. For height growth, the 100% Douglas-fir plots were different from the other levels. Volume was different between the 100% Douglas-fir level and the 100% and 75% western redcedar levels, but was not different from the 50% western redcedar level of mixture. Significant differences in crown area were detected between the 100% western redcedar level and the 50% and 100% Douglas-fir levels of mixture.

This research examines the growth and survival of western redcedar and Douglas-fir planted at different densities and at different levels of mixtures. After 14 years, treatment averages for dbh, height growth, volume, and crown area were significantly different across mixtures; the greater the proportion of Douglas-fir present in the treatment, the greater the average dbh, height growth, volume, and crown area. As expected, the early height growth of Douglas-fir appears to be outperforming that of western redcedar; height growth of Douglas-fir was about twice that of western redcedar. Similarly, Douglas-fir dbh is more than twice that of western redcedar. When the species were analyzed independently, no statistically significant effects were evident, which indicates no intraspecific effect on growth and survival. Although not statistically significant, average dbh, volume, and crown area did tend to be larger for individual species in the 1:3 mix than for the 1:1 mix or pure stands, which indicates that the 1:3 mix may better optimize the ecological combining ability of the two species.

Density did not have a significant effect on any of the response variables we analyzed after 14 years of growth. The literature indicates that if competition between individual trees was occurring, we would expect a density effect on dbh (Lanner 1985) and hence volume, and an effect on survival (Reineke 1933; Yoda et al. 1963; Curtis 1970; Long and Smith 1984). We surmise that the trees were not old enough or big enough for us to detect these effects; however, as density increased for all trees combined, average dbh and crown area did tend to decrease. If this trend continues, we expect to see significant differences in dbh and crown area. Initial spacing does not seem to affect height growth (e.g., Seidel 1984; Lanner 1985; Smith et al. 1997) except at high densities (Oliver and Larson 1996; Smith et al. 1997), so we did not expect or see a density effect on height growth.

The trees in this experiment are still young. As the trees age, we expect to see more significant results that will be of interest to forest managers. The importance of western redcedar on the coast of British Columbia is increasing. Therefore, we wanted to make early results available to practitioners. Continued monitoring of this experiment will examine the dynamics of mixed Douglas-fir and western redcedar plantations and the long-term benefits of mixed stands for producing timber volume.

7 CONCLUSION

As expected, the average early growth of Douglas-fir was significantly greater than that of western redcedar; however, average growth of Douglas-fir or western redcedar was not significantly different when grown in a pure stand compared to a 1:1 or 1:3 mix of the two species. Average growth of either species was also not significantly different at densities of 500, 1000, or 2000 stems per hectare. Consequently, at this young age, the effect of the species mixtures on growth is due to the different growth rates of the two species (and perhaps the morphological characteristics of the two species) and not the result of interspecific competition being greater or lesser than intraspecific competition. Continued monitoring of this experiment will study species dynamics, as well as the perceived long-term benefits of mixed stands in promoting ecosystem resilience for timber supply in the face of climate change.

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